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HOW DO PUPILS PERCEIVE EDUCATIONAL ROBOTICS AS A TOOL TO IMPROVE THEIR 21ST CENTURY SKILLS?

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In the past years, the use of educational robots has steadily increased, in particular due to the ongoing digitalization of modern societies and the new skills that professions require. It has been argued that educational robotics activities have the potential to promote the acquisition of such skills and may increase pupils' interest in STEM disciplines. Despite these results, only few studies have examined the pupils' perspective regarding the pedagogical value of educational robotics in formal education. Therefore, in this study with 91 pupils aged between 13 and 15 years, we aimed at investigating how pupils perceive educational robotics as a tool to improve their creativity, collaboration, computer science and computational thinking skills and to foster their interest in STEM disciplines. Over a period of one semester, the pupils worked with the robot Thymio II and evaluated their experience through a questionnaire. The results showed that boys and girls have different perceptions on which competences they could enhance: while

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boys affirmed more often than girls, that they could improve their computer science and computational thinking skills, the opposite was found for collaboration and creativity. Moreover, the results illustrated that educational robotics activities could increase the interest in coding, computer science and engineering, however, this was predominantly observed in boys.

1 Introduction

Recently, there has been an increased interest of using educational robots in formal education settings. This ongoing trend of introducing robots into classrooms is motivated by several reasons. On the one hand, it has been argued, that educational robotics can provide a hands-on and motivating teaching tool to introduce pupils to science, technology, mathematics and engineering (STEM) (Park & Han, 2016). STEM skills are considered essential for the 21st century workforce and are required for many professions (Erdogan *et al*., 2017). With respect to the challenges ahead of digital societies, there is an increased interest in motivating coming generations to pursue careers in these areas. In this regard, there is a desire to particularly encourage girls. Females are still under-represented in these disciplines (Hill *et al*., 2010): for example, the worldwide average of women researchers in science in 2015 was only 28.8% (UNESCO, 2018). This is also due to social and environmental factors like the stereotype that boys are better than girls in math and science, or social biases that implicitly associate science and math with males and humanities and arts with females (Hill *et al*., 2010). These factors influence girls' likelihood of cultivating their own interest in math and science and pursuing a career in those fields. It is hoped, that early exposure to educational robotics activities, could counteract this trend, since educational robotics can provide exciting and attractive gender-neutral learning environments to arouse interest and curiosity for STEM disciplines in both boys and girls (Weinberg *et al*., 2007).

However, when working with educational robots, the goal is not only that pupils learn about robotics and the related STEM disciplines, but it is also intended that they acquire important transversal skills, such as creativity, collaboration and computational thinking. Those skills together with digital skills are considered fundamental for future workplaces and are seen as key competences of the 21st century (World Economic Forum, 2016). Previous studies have acknowledged that their development can be fostered through activities involving educational robotics. Indeed, in many educational robotics activities the pupils are called to use their creativity to design and construct robots, as well as to develop problem solutions to perform robotic tasks (e.g. Park & Hahn, 2016). Moreover, educational robotics activities often require pupils to work and collaborate in groups in order to achieve their goals, hence promoting collaborative work and communication strategies (Nugent *et al*., 2010;

Ardito *et al*., 2014). Most recently, particular attention has been devoted to the use of educational robotics for teaching skills related to computational thinking. Popularized by Wing (2006), computational thinking involves "solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science" (p.33) and is considered a fundamental competence for modern societies. In this context, previous work has acknowledged the potential of educational robotics to promote the development of computational thinking (Atmatzidou & Demetriadis, 2016).

Nevertheless, it appears that so far only few studies have focused on the pupils' perspective regarding the perceived pedagogical value of educational robotics activities. In the past, some studies intended to examine if pupils perceived a development of their 21st century competences or an increased interest in STEM disciplines following educational robotics activities. Naizer *et al*., (2014) for example, analysed the interest and the confidence regarding math, science, technology, and problem-solving by 32 predominantly sixth graders schoolchildren during a summer camp, showing a positive impact on females' beliefs about their abilities in those areas. In another study, Welch (2010) could observe in high school students a more positive attitude toward sciences after their participation in an educational robotics competition. Similarly, the study of Theodoropoulus *et al*., (2017) addressed student's attitudes towards STEM and 21st century skills. In their study with 30 pupils, they reported improved collaboration, problem solving and creativity skills as well as a better understanding of STEM concepts, and a gain in programming knowledge in pupils that participated in an educational robotics competition. Another study by Kaloti-Hallak *et al*., (2015) instead, showed that there was no significant change in the pupils' motivation to learn STEM disciplines following the participation in a robotic competition. However, the authors also explained that they could not measure a significant increase, because the motivation was already very high at the beginning. Nugent *et al*., (2010) have analysed the impact of robotics on middle school students' learning and attitudes toward STEM. The pupils participated either in a 40 hours school camp or in a condensed 3 hours event. Results showed that the school camp led to significantly greater learning, whereas the short-term intervention primarily positively affected the attitude and motivation.

However, these studies have included rather limited samples of pupils (Naizer *et al*., 2014; Theodoropoulus *et al*., 2017) or have analysed the perspective of the pupils after comparatively short interventions (Naizer *et al*., 2014; Welch, 2010). Additionally, many of the results were derived from activities related to extracurricular robotic competitions (Kaloti-Hallak *et al*., 2015; Theodoropoulus, 2017; Welch, 2010) or summer camps (Naizer *et al*., 2014; Nugent *et al*., 2010), with some including unrepresentative samples (i.e., very talented and/or motivated pupils), selected either by their teachers or by self-enrolment (Kaloti-Hallak *et al*., 2015; Naizer *et al*., 2014; Welch, 2010). In contrast, pupils' perceptions on educational robotics activities after long-term interventions in formal education settings including all pupils of a class, still seem to be unexplored.

Therefore, this study with 91 pupils aged between 13 and 15 years, aims at examining the pupils' perspective on educational robotics activities in formal education settings: this work investigates if pupils believe that through educational robotics activities in class they can improve their creativity, collaboration, computer sciences and computational thinking skills. Moreover, it examines if the educational robotics activities increased the pupils' interest in STEM disciplines and whether there are differences according to the gender of the pupils. Specifically, this study aims at addressing the following research questions:

1. Do pupils believe that through educational robotics activities in formal education settings they can improve their creativity, collaboration, computational thinking and computer sciences skills?
2. Do educational robotics activities in formal education settings increase pupils' interest in STEM disciplines?
3. Are there differences in the questions 1 and 2 according to the gender?

2 Methods

2.1 Participants and procedure

The study was carried out in Ticino, an Italian speaking Canton in southern Switzerland. The participants of this study were 91 pupils (41 females (45%), 49 males (54%), 1 without indication (1%)) from four different 3rd grade classes of the lower secondary school of Castione, a suburban town in Ticino. The majority of the children (80%) were born in 2005 and were therefore 13 years old during the study. 13% were born in 2004 and 3% in 2003. The rest (4%) did not answer this question. For almost all participants it was the first time that they worked with an educational robot. As a matter of fact, educational robotics and more in general computer sciences are only marginally part of the compulsory school curriculum in Ticino. It is hence often a decision of the teachers to carry out such activities that are classified as general training, i.e., skills that are not part of one or more specific disciplines, but involve all disciplines, and are therefore mostly done in form of school projects that last normally only a few days. For this project however, the pupils could work with the educational robot Thymio II[1], hereafter referred to as Thymio, during a whole semester, since the teachers of the four classes that participated in

[1] Thymio is s an educational robot designed at EPFL in 2010-11. It aims to be gender-neutral: it is all white with a very clean and functional shape (Chevalier et al., 2016).

the survey were enrolled in a Certificate of Advanced Studies in Educational Robotics where they learned how to bring educational robotics into classes. As part of this training, the teachers were asked to perform different robotics activities with their classes to teach them how to use and program Thymio. Therefore, the pupils worked one complete semester with Thymio, most of the time in small groups. The amount of time spent with Thymio however, depended on the teacher and was different for each class. During these activities (e.g. program Thymio so that it can serve a snack during the break; program Thymio in order to create a light painting, etc.), the pupils, while working in groups, had to decide on a strategy to solve the task and then program Thymio to implement their solution.

At the end of the school year, the pupils were asked to complete a questionnaire reflecting on their experience during the whole semester.

2.2 Instruments

In order to collect the data an in-house developed questionnaire was used. The questionnaire included open question items as well as 5-point Likert scale questions (e.g. 1 = "I completely disagree" to 5 = "I completely agree") and simple yes/no items. The pupils were asked to indicate how much they think they have improved in four different dimensions:

- collaboration (3 items, Cronbach's alpha =.671, e.g. "with the robotics activities I learned to work with my peers"),
- creativity (3 items, Cronbach's alpha =.679, e.g. "the robotics activities allow to improve the creativity"),
- computational thinking (CT) (3 items, Cronbach's alpha =.513, e.g. "with the robotics activities I learned to decompose problems in various sub-problems")
- computer sciences skills (CS) (3 items, Cronbach's alpha =.542, e.g. "with the robotics activities I learned how a sensor works").

The Cronbach's alpha values used to estimate the reliability of the scales are between.513 and.679. Although these values are rather low, they are considered acceptable for social sciences and for small scales as evidenced by Pallant (2013).

Furthermore, some questions were dedicated to exploring if robotics activities could improve the pupils' interest toward:

- scientific disciplines (e.g. "the robotic activities improved my interest toward scientific disciplines (e.g. sciences and mathematics))"
- coding (e.g. "the robotic activities improved my interest toward coding"),
- computer sciences (e.g. "the robotic activities improved my interest to-

ward computer sciences (e.g. how does a computer/robot work)",
- engineering (e.g. "the robotic activities improved my interest toward engineering (e.g. how is a robot built))".

2.3 Data analyses

Data analyses were conducted using descriptive statistics to measure the perceived improvement in the different dimensions by the pupils and independent sample t-tests were used to analyse the differences between gender. Cohen's d was used to estimate the effect size. Missing values were pairwise excluded.

3 Results

In general, the pupils appreciated to work with Thymio. Only one child stated that he/she did not enjoy working with the robot and three left this question unanswered. The majority of the children (79%) also agreed or strongly agreed that the activities with Thymio were interesting and only 3% did not agree on this item. The rest of the children did not answer (4%) or affirmed that they neither agree nor disagree (14%). The descriptive statistics of the perceived improvement by the pupils in the dimensions collaboration, creativity, CT and CS shows mean values between 3.45 (CT) and 3.99 (collaboration) on a scale from 1 (no improvement) to 5 (high improvement), indicating that pupils believed that through educational robotics activities they could improve in all four dimensions (table 1). The highest perceived improvements were found in collaboration and creativity, thus in the two dimensions related to transversal skills (table 1).

Table 1
IMPROVEMENT IN THE FOUR DIMENSIONS THROUGH EDUCATIONAL ROBOTICS

	N	Min.	Max.	Mean	SD
Collaboration	90	1	5	3.99	.95
Creativity	89	1	5	3.93	.85
CT	89	1	5	3.45	.81
CS	91	1	5	3.66	.82

Moreover, the comparison of the perspective of female and male pupils, revealed that females compared to males perceived a higher improvement through educational robotics activities in the two dimensions collaboration (4.22 vs. 3.77) and creativity (4.00 vs. 3.89). In contrast, males perceived a higher improvement than females in the two other dimensions, namely CT (3.84 vs. 3.44) and CS (3.52 vs. 3.35) (table 2).

Table 2
IMPROVEMENT IN THE FOUR DIMENSIONS THROUGH EDUCATIONAL ROBOTICS BY GENDER

	Gender	Min.	Mean	SD
Collaboration	Female	40	4.22	.80
	Male	49	3.77	1.03
Creativity	Female	41	4.00	.77
	Male	47	3.89	.91
CT	Female	40	3.35	.92
	Male	48	3.52	.71
CS	Female	41	3.44	.74
	Male	49	3.84	.85

To analyse whether those differences are significant we conducted a t-test for independent samples. The results in table 3 show a significant difference in the dimensions "collaboration" (p=.026) and "CS" (p=.022) while there were no significant differences in the other two dimensions. The effects are medium-sized with respect to Cohen's d reaching an effect size of.49 and.50. Female pupils therefore tend to perceive a higher improvement in their collaboration skills than male pupils, while the latter perceive a higher improvement in their CS skills.

Table 3
T-TEST OF THE IMPROVEMENT IN THE FOUR DIMENSIONS THROUGH EDUCATIONAL ROBOTICS BY GENDER

	T	df	P-value.	Mean Difference	Sts. Error Difference	Cohen's d
Collaboration	2.264	87	.026	.45	.20	.49
Creativity	.584	86	.561	.11	.18	.13
CT	-.979	86	.330	-.17	.17	.21
CS	-2.339	88	.022	-.40	.17	.50

Finally, analyses have been conducted to explore whether pupils believed that thanks to educational robotics activities their interest in sciences, coding, computer sciences and engineering has improved. In general, it emerges that especially male pupils agree that their interest in all four dimensions has improved, though for some dimensions the mean value was just above 3 indicating a rather indifferent answer ("I neither agree nor disagree") (Table 4). The highest mean value for male pupils was found in the dimension "coding" (3.98). Female pupils however, were less convinced about the impact of educational robotics on their interest for the mentioned dimensions. For example, they rather disagreed that the educational robotics activities improved their interest in sciences (2.85) and engineering (2.83). A light agreement was found in the dimension computer sciences (3.41).

Table 4
INTEREST IMPROVEMENT BY GENDER

	Gender	Min.	Mean	SD
Thanks to robotics my interest in sciences has improved	Female	41	2.85	1.08
	Male	44	3.14	1.07
Thanks to robotics my interest in coding has improved	Female	41	3.05	1.18
	Male	48	3.98	1.00
Thanks to robotics my interest in computer sciences has improved	Female	41	3.41	1.34
	Male	48	3.79	1.11
Thanks to robotics my interest in engineering has improved	Female	41	2.83	1.43
	Male	49	3.73	1.10

Also for this case a t-test was conducted to analyse whether the differences were significant. Significant differences were found in the dimensions "coding" (p=.000) and "engineering" (p=.001). In both cases, as shown by the descriptive results, male pupils agreed that their interest has improved, in contrast to female pupils, who rather disagreed (table 5). The effects are medium-large with respect to Cohen's d reaching an effect size of.85 and.70, respectively.

Table 5
T-TEST OF INTEREST IMPROVEMENT BY GENDER

	T	df	P-value.	Mean Difference	Sts. Error Difference	Cohen's d
Thanks to robotics my interest in sciences has improved	-1.209	83	.230	-.28	.23	.27
Thanks to robotics my interest in coding has improved	-4.023	87	.000	-.93	.23	.85
Thanks to robotics my interest in computer sciences has improved	-1.451	87	.150	-.38	.26	.31
Thanks to robotics my interest in engineering has improved	-3.344	87	.001	-.90	.27	.70

Conclusion

The aim of this paper was to analyse how pupils perceive educational robotics activities in formal education settings as a tool to improve their creativity, collaboration, CT, CS skills and interest in STEM disciplines and if there are differences according to gender.

The results showed that pupils were generally interested in working with Thymio and that they believed that through educational robotics activities they could improve their 21^{st} century skills. However, the highest perceived improvements were found in the two transversal skill dimensions (i.e., collaboration and creativity) and not in the two "technical" skill dimensions (i.e., computational thinking and computer science). This result could surprise, since it could be expected that educational robotics has an impact especially on technical dimensions such as CT and CS skills. However, there have been different surveys that highlight how educational robotics activities are used in class with a pedagogical approach that promotes transversal skills like collaboration and creativity (Nugent *et al*., 2010; Ardito *et al*., 2014; Park & Hahn, 2016).

Moreover, the results illustrated gender differences on the perceived impact. Female pupils perceived a higher improvement through educational robotics activities in the two dimensions collaboration and creativity while male pupils perceived a higher improvement in the two technical dimensions, namely CT and CS skills. The differences were statistically significant in the two dimensions collaboration and CS skills. Although the data from this study is not sufficient to comprehensively explain these differences, some hypotheses can be formulated based on the results of previous works. Hill *et al*., (2010) showed how stereotypes and biases influence girls' likelihood of choosing STEM disciplines and how they could have a negative impact on girls' interest toward these fields. It is possible that teachers unconsciously reinforce these stereotypes by assigning different tasks to girls and boys when working in groups or even that the stereotypes lead pupils to choose specific tasks themselves: it might be that girls tend to choose creative tasks that are considered more "feminine" (for example preparing and decorating the playground where Thymio moves) while boys are more keen to choose programming tasks. In this context, it could be interesting for further studies to examine how pupils choose and divide their tasks in groups when working with robots and whether teachers assign different kinds of tasks to boys and girls.

The above-mentioned results can also be linked to the second question addressed in this study, namely if educational robotics activities help to increase pupils' interest in sciences, coding, computer sciences and engineering. In general, it emerges that especially male pupils agree that their interest has improved, especially for coding. Female pupils however, seem to be less convinced about the impact of educational robotics on their interest for those fields. A light agreement was found only for the computer sciences dimension. Significant differences were found in the dimensions "coding" and "engineering" where in both cases male pupils agreed that their interest has improved while females disagreed. These results compel us to reflect on the impact of educational robotics activities on the interest in STEM, since previously it has been argued that robotics should help to promote STEM disciplines, especially in girls (Park & Han, 2016). To reach this objective, teachers should however be aware of the gender differences and on how to stimulate girls in those fields in order to dismantle the gender stereotypes that are most probably already present in pupils.

Summarizing we can say that pupils appreciated to work with Thymio and that they believed that those activities can have an impact on their collaboration, creativity, CT and CS skills. The perceived impact was different for male and female pupils, with males tending to perceive a higher impact on the technical skills and females on their collaboration and creativity skills. However, only little impact could be found on the interest in sciences, coding, computer sciences and engineering and in this case, predominantly boys reported an increased interest.

The present study was conducted with pupils of four different classes of the same school, hence generalization is limited. Furthermore, the questionnaire addressed only a few questions for each of the analysed dimensions and it covered only some elements of the corresponding concepts. For example, the concepts of CT or CS skills are more articulated and cannot be extensively covered with a scale of only three items each. More in depth studies in this field with more reliable scales are hence desirable. Nevertheless, the presented study gives a new perspective on the impact of educational robotics activities that have been carried out during a longer period in formal education settings and gives some first insights on the perceptions of pupils, while differentiating between genders.

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